

NUMERICAL SIMULATIONS ON THE EFFECTS OF USING VENTILATION
FAN ON CONDITIONS OF AIR INSIDE A CAR PASSENGER COMPARTMENT

INTAN SABARIAH BINTI SABRI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

MARCH 2014

To my beloved...
father, Sabri bin Abdullah
mother, Rebeah bt Hj. Harun
brothers, sisters-in-law,
nieces and my nephews.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and the Most Merciful

First and foremost, I would like to express my deepest gratitude to Allah swt for giving me an opportunity, strength and His guidance to complete this research on time. With His blessings may this work be beneficial for the whole of mankind.

I am deeply indebted to my supervisor, Dr. Haslinda bt Mohamed Kamar for her constant encouragement, guidance, understanding, motivation as well as valuable advice throughout the completion of this research. My special thanks extended to my co-supervisor, Associate Professor Dr Nazri bin Kamsah for his support, patience and guidance throughout this research. He has taught me his professionalism and the profound art of research which inevitably is reflected in this thesis.

I am indebted to University Teknologi Malaysia (UTM) and Ministry of Higher Education (MOHE) for funding this Master's study as well as Research Management Centre (RMC), UTM (Vot No. 00G41) for financial support.

My utmost appreciation goes to my beloved parents and siblings for their love, understanding and endlessly praying for my success. My appreciation also extended to my dearest friends for their moral support and friendship. To my greatest friend, Nik Nabilah Nik Mohd Naser, thank you for your supports and patience throughout this friendship. May Allah bless all of us.

ABSTRACT

The use of a mechanical ventilation fan is one strategy that can be employed to reduce high air temperature build up in a car passenger compartment when it is parked in the sun. This study developed a numerical simulation to investigate the effects of using a ventilation fan on the air temperature inside the passenger compartment when it is parked in the open space during a sunny day. A computational fluid dynamics (CFD) method was used to perform the numerical simulations. FLUENT software was employed to develop the passenger compartment model and simulate the air flow conditions inside the passenger compartment. The validation of the numerical simulation was done by comparing the air temperatures from the CFD simulation results against the air temperatures at two selected points obtained from the field measurement from 12 pm to 3 pm. On average, the air temperature prediction at the front and rear compartment show good agreement with the measured data, with a difference of about 2.5% and 1.6%, respectively. The validated numerical simulation was used to perform a parametric study to investigate the effects of the ventilation fan location, number of the ventilation fans as well as the air velocity at the ventilation fans, on the air temperature and air flow pattern inside the passenger compartment. A three-dimensional (3D) steady-state simulation results show that placing one ventilation fan at the rear deck with an air velocity of 2.84 m/s reduces the air temperature at the front and rear compartment by 4°C. Placing four ventilation fans at the roof lowers the air temperatures at the front and rear compartments by 6°C and 7°C, respectively. Increasing the air velocity from 2.84 m/s to 15.67 m/s at four ventilation fans placed at the roof suggests the highest reduction of the air temperature inside the passenger compartment by 8°C.

ABSTRAK

Penggunaan kipas pengudaraan mekanikal merupakan satu strategi yang boleh digunakan untuk mengurangkan suhu udara yang tinggi di dalam ruang penumpang sebuah kereta apabila ianya diletakkan di bawah sinaran matahari. Kajian ini membangunkan simulasi berangka untuk menyiasat kesan-kesan penggunaan kipas pengudaraan terhadap suhu udara di dalam ruang penumpang sebuah kereta apabila ianya diletakkan di kawasan terbuka pada hari yang panas terik. Kaedah Perkomputeran Dinamik Bendalir Berbantuan Komputer (CFD) digunakan untuk melakukan simulasi berangka. Perisian FLUENT digunakan untuk membangunkan model ruang penumpang dan mensimulasi keadaan aliran udara di dalam ruang penumpang. Pengesahan simulasi berangka telah dilakukan dengan membandingkan suhu udara daripada simulasi berangka dengan suhu udara pada dua titik yang diperolehi daripada pengukuran sebenar daripada pukul 12 tengahari hingga 3 petang. Secara purata, ramalan suhu udara pada ruang hadapan dan belakang menunjukkan persetujuan yang baik dengan data yang diukur, dengan perbezaan masing-masing adalah sebanyak 2.5% dan 1.6%. Simulasi berangka yang telah disahkan digunakan untuk melaksanakan kajian parametrik untuk menyiasat kesan-kesan lokasi kipas pengudaraan, bilangan kipas pengudaraan dan juga halaju udara pada kipas pengudaraan, ke atas suhu udara dan corak aliran udara di dalam ruang penumpang. Keputusan simulasi keadaan mantap tiga dimensi (3D) menunjukkan bahawa meletakkan satu kipas pengudaraan pada dek belakang dengan halaju udara 2.84 m/s mengurangkan suhu udara pada ruang hadapan dan belakang sebanyak 4°C. Meletakkan empat kipas pengudaraan pada bumbung menurunkan suhu udara pada ruang hadapan dan belakang masing-masing sebanyak 6°C dan 7°C. Peningkatan halaju udara pada empat kipas pengudaraan yang diletakkan pada bumbung daripada 2.84 m/s kepada 15.67 m/s menunjukkan pengurangan suhu udara tertinggi di dalam ruang penumpang iaitu sebanyak 8°C.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	NOMENCLATURE	xvi
	LIST OF APPENDICES	xix
1	INTRODUCTION	
	1.1 Introduction	1
	1.2 Problem Statement	2
	1.3 Objectives of the Study	3
	1.4 Scopes of Study	4
	1.5 Thesis Outline	4
2	LITERATURE REVIEW	
	2.1 Introduction	6
	2.2 Heat Gain through Glass Windows	7
	2.3 Heat Gain inside the Passenger Compartment through Car Dashboard	8
	2.4 Air Flow in CFD A analysis	9
	2.5 Ventilation System	14

3	RESEARCH METHODOLOGY	
3.1	Introduction	20
3.2	Field Measurement	21
3.3	CFD Simulation	25
3.3.1	CFD Analysis Process	25
3.3.2	Model of Geometry	26
3.3.3	Generation of Grid	28
3.3.4	Solver	30
3.3.5	Pressure-Velocity Coupling	31
3.3.6	Basic Governing Equations	31
3.3.7	Boundary Conditions	34
3.3.7.1	Wall Boundary Condition	36
3.3.8	Material Properties	36
3.3.9	Verification of the Simulations	37
3.3.9.1	Grid Independence Test	37
3.3.9.2	Convergence	38
3.4	Validation	39
3.5	Turbulent Flow Analysis	40
3.5.1	Turbulence Model	40
3.5.2	Boundary Conditions for Turbulence Analysis	42
3.5.2.1	Pressure Inlet Boundary Condition	43
3.5.2.2	Velocity Inlet Boundary Condition	44
3.5.2.3	Wall Function	45
3.5.3	Under-Relaxation Factors	46
3.6	Baseline Case	47
3.7	Parametric Study	49
3.7.1	Effect of the Ventilation Fan Location	50
3.7.3.1	One Ventilation Fan at the Middle of the Roof	50
3.7.2	Effects of the Number of the Ventilation Fan	51
3.7.2.1	Two Ventilation Fans at the Rear Deck	51
3.7.2.2	Three Ventilation Fans at the Rear Deck	52
3.7.2.3	Two Ventilation Fans at the Roof	53
3.7.2.4	Four Ventilation Fans at the Roof	54

	3.7.3 Effects of Outlet Air Velocity at the Ventilation Fan	55
4	RESULTS AND DISCUSSIONS	
	4.1 Introduction	56
	4.2 Validation of the CFD Simulation	56
	4.3 Baseline Case	61
	4.4 Results of Parametric Study	65
	4.4.1 Effects of Ventilation Fan Location	66
	4.4.1.1 One Ventilation Fan Placed at the Roof	66
	4.4.2 Effects of Number of Ventilation Fans	69
	4.4.2.1 Two Ventilation Fans Placed at the Rear Deck	69
	4.4.2.2 Three Ventilation Fans Placed at the Rear Deck	72
	4.4.2.3 Two Ventilation Fans Placed at the Roof	75
	4.4.2.4 Four Ventilation Fans Placed at the Roof	78
	4.4.3 Effects of Air Velocity at the Ventilation Fan	81
	4.4.3.1 One Ventilation Fan Placed at the Rear Deck	82
	4.4.3.2 Two Ventilation Fans Placed at the Rear Deck	85
	4.4.3.3 Three Ventilation Fans Placed at the Rear Deck	88
	4.4.3.4 One Ventilation Fan Placed at the Roof	91
	4.4.3.5 Two Ventilation Fans Placed at the Roof	94
	4.4.3.6 Four Ventilation Fans Placed at the Roof	97
	4.5 Summary	101
5	CONCLUSIONS AND RECOMMENDATIONS	
	5.1 Conclusions	106
	5.2 Recommendations for Future Work	107
	REFERENCES	108
	APPENDICES A - C	114

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	The range and accuracy of measuring instruments	22
3.2	Temperature boundary conditions for 12 pm to 3 pm analysis	35
3.3	Materials properties used on the model (Jonas Jonsson, 2007)	36
3.4	Default values of standard k - ε turbulence model constants (FLUENT 6.3 User's Guide, 2006)	41
3.5	The boundary conditions prescribed at the inlets	43
3.6	Parameters for velocity boundary condition prescribed at the ventilation fan	44
3.7	Default values of α in FLUENT	46
3.8	The descriptions of the parametric study	49
4.1	The parameters of the ventilation fan used for baseline case	61
4.2	A summary of CFD results	102

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Thermal load model on the passenger compartment (Haslinda, 2009)	6
2.2	Heat transfer through glass (Haslinda, 2009)	7
2.3	Temperature variations of the compartment equipment (Mezhrab and Bouzidi, 2006)	8
2.4	Average air temperature inside the passenger compartment (Jasni and Nasir, 2012)	19
3.1	Summary of activities in research methodology	21
3.2	Locations of thermocouples for field measurement	23
3.3	a) The Proton Saga BLM model, (b) Thermocouples placement, (c) Thermocouples placement inside the passenger compartment, (d) USB TC-08	24
3.4	Summary of activities in CFD simulation	26
3.5	A simplified CFD model of the passenger compartment	27
3.6	Multiblock Structured Grid (FLUENT 6.3 User's Guide, 2006)	29
3.7	Unstructured Tetrahedral Grid (FLUENT 6.3 User's Guide, 2006)	29
3.8	Meshing of the computational domain	30
3.9	Boundary conditions prescribed on the CFD model at 1 pm	35
3.10	The air temperature against the number of elements	38
3.11	Convergence of baseline case in steady-state	39
3.12	Boundary conditions prescribed on the passenger compartment	42

3.13	Location of the ventilation fan	47
3.14	Air flow path inside the passenger compartment	48
3.15	One ventilation fan placed at the middle of the roof	50
3.16	Two ventilation fans placed at the rear deck	51
3.17	Three ventilation fans placed at the rear deck	52
3.18	Two ventilation fans at the roof	53
3.19	Four ventilation fans at the roof	54
4.1	Contour of air temperature at 1 pm at steady-state condition: (a) Isometric view, (b) On a symmetrical plane	58
4.2(a)	The comparison between predicted and measured air temperature inside the passenger compartment	60
4.2(b)	The percentage of the deviation between predicted and measured air temperature at the front and rear compartment	60
4.3	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	63
4.4	The comparison of air temperature variation along X-X plane between no ventilation fan condition and baseline case	64
4.5	Air flow patterns at steady–state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	65
4.6	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	67
4.7	The air temperature variation along X-X plane between no ventilation fan condition, baseline case and one fan placed at the roof	68
4.8	Air flow patterns at steady–state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	69
4.9	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	70

4.10	The air temperature variation along X-X plane between no ventilation fan condition, baseline case and two fans placed at the rear deck	71
4.11	Air flow patterns at steady-state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	72
4.12	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	73
4.13	The air temperature variation along X-X plane between no ventilation fan condition, baseline case and three fans placed at the rear deck	74
4.14	Air flow patterns at steady-state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	75
4.15	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	76
4.16	The air temperature variation along X-X plane between no ventilation fan condition, baseline case and two fans placed at the roof	77
4.17	Air flow patterns at steady-state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	78
4.18	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	79
4.19	The air temperature variation along X-X plane between no ventilation fan condition, baseline case and four fans placed at the roof	80
4.20	Air flow patterns at steady-state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	81
4.21	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	83

4.22	The comparison between no ventilation fan and varying the air velocities at the ventilation fan placed at the rear deck	84
4.23	Air flow patterns at steady–state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	85
4.24	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	86
4.25	The comparison between no ventilation fan and varying the air velocities at two ventilation fans placed at the rear deck	87
4.26	Air flow patterns at steady–state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	88
4.27	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	89
4.28	The comparison between no ventilation fan and varying the air velocities at three ventilation fans placed at the rear deck	90
4.29	Air flow patterns at steady–state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	91
4.30	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	92
4.31	The comparison between no ventilation fan and varying the air velocities at one ventilation fan placed at the roof	93
4.32	Air flow patterns at steady–state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	94
4.33	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	95
4.34	The comparison between no ventilation fan and varying the air velocities at two ventilation fans placed at the roof	96

4.35	Air flow patterns at steady–state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	97
4.36	Contour of air temperature at steady-state condition: (a) Isometric view, (b) On the symmetrical plane	98
4.37	The comparison between no ventilation fan and varying the air velocities at four ventilation fans placed at the roof	99
4.38	Air flow patterns at steady–state condition: (a) far-right air vent, (b) center-right air vent, (c) far-left air vent, (d) center-left air vent	100
4.39	The air temperature variation along X-X plane for no ventilation fan condition, baseline case and various fan setting conditions with outlet air velocity of 2.84 m/s	102
4.40	The air temperature variation along X-X plane for no ventilation fan condition, baseline case and various fan setting conditions with outlet air velocity of 15.67 m/s	103

NOMENCLATURE

Roman Symbols

D	- Diameter	(cm)
v	- Air velocity	(m/s)
k	- Turbulence kinetic energy	(m ² /s ²)
t	- Time	(s)
p	- Static pressure	(Pa)
\vec{F}	- Gravitational body force and external body forces	(N)
k_{eff}	- Effective conductivity ($k + k_t$)	(W/m·K)
k_t	- Turbulent thermal conductivity	(W/m·K)
\vec{J}_j	- Diffusion flux of species j	(kg/m ² ·s)
h	- Sensible enthalpy	(h ⁰)
Y_j	- Mass fraction of species j ,	(dimensionless)
G_k	- Generation of turbulence kinetic energy due to the mean velocity gradients.	(dimensionless)
G_b	- Generation of turbulence kinetic energy due to buoyancy	(dimensionless)
$C_{1\varepsilon}$	- Constants for transport equations	(dimensionless)
$C_{2\varepsilon}$	- Constants for transport equations	(dimensionless)
$C_{3\varepsilon}$	- Constants for transport equations	(dimensionless)
S_k	- User-defined source terms.	(dimensionless)
S_ε	- User-defined source terms.	(dimensionless)
T_0	- Air temperature without ventilation fan	(°C)
T_l	- Air temperature with ventilation fan	(°C)

h	-	Convection heat transfer coefficient	(W/m ² ·°C)
P_{gauge}	-	Gauge pressure	(Pa)

Greek Symbols

ρ	-	Flow density	(kg/m ³)
ε	-	Turbulence Dissipation Rate	(m ² /s ³)
$\bar{\tau}$	-	Stress tensor	(Pa)
\vec{g}	-	Gravitational body force	(m/s ²)
μ	-	Molecular viscosity	(Pa·s)

Abbreviations

AC	-	Air-conditioning
SWL	-	Short Wavelength
LWL	-	Long Wavelength
SIMPLE	-	Semi-Implicit Method for Pressure-Linked Equations
FDM	-	Finite Difference Method
RANS	-	Reynolds Averaged Navier-Stokes
FVM	-	Finite Volume Method
PDE	-	Partial Differential Equations
EV	-	Electric Vehicle
CFD	-	Computational Fluid Dynamics
2D	-	Two-dimensional
3D	-	Three-dimensional
s2s	-	Surface-to-surface
Re	-	Reynolds

TSV	-	Thermal Sensation Value
PPD	-	Predicted Percent Dissatisfied
HVAC	-	Heating, Ventilation and Air Conditioning
RNG	-	Renormalisation group
TEG	-	Thermoelectric generators
IR	-	Infrared
UV	-	Ultraviolet

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	FIELD MEASUREMENT	114
B	SIMULATION SETTINGS IN FLUENT	116
C1	RESEARCH PUBLICATION	126
C2	POSTER PRESENTATION	137

CHAPTER 1

INTRODUCTION

1.1 Introduction

The air-conditioning (AC) system is the single largest auxiliary load on automobile engine. It was developed to provide an adequate cooling in a period of time from a hot soak condition (Rugh *et al.*, 2001). The passenger compartment experienced peak soak temperatures regarding to maximum temperature reach, while soaking in the sun (Farrington and Rugh, 2000). According to Johnson (2002), during peak soak condition the AC system can draw up to 5 to 6 kW power from the vehicle's engine. This is equivalent to a vehicle being driven down the road at 56 km/hr. The study shows that the use of AC in a conventional vehicle increases the fuel consumption by 35% or drops fuel economy by 26%. By reducing the peak soak temperatures in the passenger compartment, it could lower the AC system power consumptions (Rugh *et al.*, 2001). There are many ways for reducing the peak soak temperature such as solar reflective glazing, car shades, paint or rejecting the heat to the ambient by using active or passive ventilation of the passenger compartment while the car is parked in the sun (Bharatan *et al.*, 2007). The ventilation fan was identified as an efficient way for reducing the soak temperature inside the passenger compartment (Saidur *et al.*, 2009; Farrington and Rugh, 2000; Rugh *et al.*, 2007; Huang *et al.*, 2005).

The need to reduce the heat loads that entered the passenger compartment has become an important issue nowadays. Recently, plenty works were reported on the use of ventilation fan in reducing the soak temperatures inside the passenger compartment. The researchers investigated the effect of ventilation fan on soak temperatures experimentally as well as Computational Fluid Dynamics (CFD) approaches. Generally, the experimental approaches were time and cost consuming (Sevilgen and Kilic, 2013). As a result, in the present study, the CFD approach is adopted in developing a numerical simulation tool to investigate the effects of using the ventilation fan on the air temperature and air-flow field inside the passenger compartment when the car was parked in the sun. A simplified passenger compartment model was developed using Gambit software. Meanwhile, a numerical simulation was developed using ANSYS FLUENT software and the simulation results were presented in steady-state condition in terms of contours of air temperature and air flow pattern.

1.2 Problem Statement

The single largest auxiliary loads on automotive engine were caused by the air-conditioner compressor (Haslinda *et al.*, 2012). During the peak load it can draw up to 5 to 6 kW power from the vehicle's engine and this is equivalent to the vehicle being driven down the road at 56 km/hr (Johnson, 2002). This could lead to increased fuel consumption. When the car parked in the sun, the soak air temperature inside the passenger compartment can rise up to 60°C (McLaren *et al.*, 2005). By reducing the air temperature inside the passenger compartment, it is very significant not only for passenger comfort but also to reduce the power consumed by the AC system. The equipment inside the passenger compartment will absorb the heat from the surrounding and make the passenger compartment hard to be cooled down within a short period of time. Consequently, a driver needs to turn on the AC system with the blower set to maximum before starting to drive in order to reduce the air temperature inside the passenger compartment to a comfortable level.

Reducing the air temperature inside the passenger compartment is very important to reduce the auxiliary loads of AC that could lead to saving the fuel consumption (Farrington *et al.*, 1998). To overcome this problem, the use of ventilation fan was identified as an efficient way for lowering down the air temperature inside the passenger compartment (Saidur *et al.*, 2009). To assess the effectiveness of ventilation fan, it is necessary to investigate the air temperature inside the passenger compartment. This can be achieved by means of performing the numerical simulation using CFD method. The numerical simulation was validated by comparing the air temperatures from the numerical simulation against the actual air temperatures data at two selected points obtained from the field measurement, when the car was parked in the sun from 12 pm to 3 pm.

1.3 Objectives of the Study

Accordingly, the objectives of this study are:

1. To estimate the air temperatures at two selected points without ventilation fan inside the passenger compartment when the car is parked in the sun.
2. To investigate the effect of ventilation fan on the air temperature and air-flow field inside the passenger compartment.
3. To perform a parametric study to investigate the influence of the ventilation fan location, number of the ventilation fans used and outlet air velocity at the ventilation fan on the air temperature and air-flow field inside the passenger compartment.

1.4 Scopes of Study

Towards achieving the objectives, several research scopes have been determined and listed as follows:

1. A three-dimensional (3D) model of Proton Saga BLM passenger compartment as the computational domain.
2. Ventilation fan as available in the market.
3. Steady-state operating condition, after the air temperature is reduced by the fan.
4. Without passenger.
5. Without AC system.
6. Thermal loading during parking in a sunny day condition.
7. Validation of the numerical simulation was done against the measured air temperature at two selected points obtained from the field measurement.

1.5 Thesis Outline

Chapter 2 discusses a review on the air temperature distributions and air-flow field inside the passenger compartment and method to reduce the air temperature inside the passenger compartment during parking condition.

Chapter 3 describes the development of the numerical simulation of passenger compartment model of Proton Saga BLM using CFD FLUENT software. The boundary conditions are specified accurately on the passenger compartment model based on the actual measurement. A validation of the numerical simulation was

done by comparing the air temperatures from the numerical simulation against the actual air temperatures data at two selected points obtained from the field measurement. A parametric study is also described.

In Chapter 4, the results of the baseline case and parametric study are presented in terms of contours of air temperature as well as air flow patterns at steady-state conditions. The effects of the ventilation fan location, number of the ventilation fans used and the outlet air velocity at the ventilation fan on the air temperature and air-flow field inside the passenger compartment are discussed in details.

Finally, the conclusions and recommendations for the future study are discussed in Chapter 5.

REFERENCES

- Abd-Fadeel A. W. and Hassanein A. S. (2013). Temperature Variations in A Parked Car Exposed to Direct Sun during Hot and Dry Climates. *International Journal of Automobile Engineering Research & Development (IJAuERD)*. Vol. 3(1), 75-80. ISSN 2277-4785.
- Alexandrov A., Kudriavtsev V., and Reggio M. (2001). Analysis of Coupled Internal-External Flows and Ventilation in a Generic Passenger Car. *ASME-PUBLICATIONS-PVP*. 424(2001) 127-132.
- Alexandrov A., Kudriavtsev V., and Reggio M. (2001). Analysis of Flow Patterns and Heat Transfer in Generic Passenger Car Mini-Environment. *In 9th Annual Conference of the CFD Society of Canada*. 27-29 May 2001. Kitchener, Ontario.
- Al-Kayiem H. H, Sidik M. F.M. and Munusammy L. A. R. Y. (2010). Study on the Thermal Accumulation and Distribution inside a Parked Car Cabin. *American Journal of Applied Sciences*. 6, 784-789. ISSN 1546-9239. 2010 Science Publications.
- Aroussi A., Hassan A., and Morsi Y. (2003). Numerical Simulation of the Airflow Over and Heat Transfer Through a Vehicle Windshield Defrosting and Demisting System. *Heat and Mass Transfer*. 39 (5-6) (2003) 401-405.

ASHRAE Handbook Fundamentals, 1993. HVAC Applications. American Society of Heating, Refrigerating and Air-Conditioning Engineers. <http://www.ashrae.com>.

Bharathan D., Chaney L., Farrington R. B., Lustbader J., Keyser M. and Rugh J. (2007). An Overview of Vehicle Test and Analysis Results from NREL's A/C Fuel use Reduction Research. *In Proceedings of the Vehicle Thermal Management Systems Conference & Exhibition (VTMS-8)*. 20-24 May. Nottingham, England. NREL/CP-540-41155.

Dadour, I.R., Almanjahie, I., Fowkes, N.D., Keady, G., and Vijayan, K. (2011). Temperature Variations in a Parked Vehicle. *Forensic Science International*. 207(1) (2011) 205-211.

Dengchun Zhang and Peifen Weng (2007). Numerical Simulation and Experiment Research of Air Organization in Air-conditioned Passenger Car. *Proceedings of Building Simulation 2007*. Beijing.

Farrington R. and Rugh J. (2000). Impact of Vehicle Air-Conditioning on Fuel Economy, Tailpipe Emission and Electric Vehicle Range. *NREL Report No. CP-540-28960*, Golden, CO; NREL.

Farrington R. B., Brodt D. L., Burch S. D. and Keyser M. A. (1998). Opportunities to Reduce Vehicle Climate Control Loads. *In Proceedings of the 15th Electric Vehicle Symposium*. 30 September – 3 October. Brussels, Belgium.

Farrington R., Anderson R., Blake D., Burch S. Cuddy M., Keyser M. and Rugh J. (1999). Challenges and Potential Solutions for Reducing Climate Control Loads in Conventional and Hybrid Electric Vehicles. *Presented at the VTMS4*.

FLUENT 6.3 User's Guide (2006). Fluent Inc., Lebanon, NH 03766.

Google (2013). Available at [http://en.wikipedia.org/wiki/Ventilation_\(architecture\)](http://en.wikipedia.org/wiki/Ventilation_(architecture))
(Accessed at 10 August 2013).

Haslinda Mohamed Kamar (2009). *Computerised Simulation of Automotive Air Conditioning System*. Ph.D. Thesis. Universiti Teknologi Malaysia.

Huang K. D., Tzen S. C., Ma W. P. and Wu M. F. (2005). Intelligent Solar-Powered Automobile-Ventilation System. *Applied energy*. 80(2) (2005) 141-154.

Ivanescu M., Neacsu C.A. and Tabacu I. (2010). Studies of the Thermal Comfort of the Passenger Compartment Using Numerical Simulation. *International Congress Motor Vehicles and Motors 2010*. Kragujevac, October 7th-9th, 2010. MVM2010-026.

Jaiswal K. G., Gandhi M. Phalgaonkar S. and Upadhyay H. (2012). Design of A Smart Ventilation System for a Parked Car. *International Journal on the Theoretical and Applied Research in Mechanical Engineering (IJTARME)*. Volume 1. Issue 1, 2012. ISSN (Print): 2319-3182.

Jalil J. M. and Alwan H. Q. (2007). CFD simulation for a Road Vehicle Cabin. *Engineering Science*. Vol 18(2). Pp 123-142.

Jasni M. A. and Nasir F. M. (2012). Experimental Comparison Study of the Passive Methods in Reducing Car Cabin Interior Temperature. *International Conference on Mechanical, Automobile and Robotics Engineering (ICMAR)* 2012. Penang, Malaysia.

- Johnson V. H. (2002). Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort Based Approach. *Proceeding of Future Car Congress 2002*. Paper (2002-01-1957).
- Jonas Jonsson (2007). *Including Solar Load in CFD Analysis of Temperature Distribution in a Car Passenger Compartment*. Lulea University of Technology, Sweden. Master's Thesis.
- Kamar H. M., Senawi M. Y. and Kamsah N. B. (2012). Computerized Simulation of Automotive Air-Conditioning System: Development of Mathematical Model and Its Validation. *International Journal of Computer Science Issues (IJCSI)*. Vol. 9 (Issue 2, No 2). ISSN (Online): 1694-0814.
- Kilic M. and Sevilgen G. (2009). Evaluation of Heat Transfer Characteristics in an Automobile Cabin with a Virtual Manikin during Heating Period. *Numerical Heat Transfer. Part A: Applications*. 56 (6).Pp 515-539.
- Leong J. C., Tseng C.-Y., B.-D. Tsai B.-D. and Hsiao Y.-F. (2010). Cabin Heat Removal from an Electric Car. *World Electric Vehicle Journal*. Vol. 4 - ISSN 2032-6653.
- Limaye V. M., Deshpande M. D., Sivapragasam M., and Kumar V. (2012). Design of Dynamic Air Vents and Airflow Analysis in a Passenger Car Cabin, *SASTECH*. Volume 11, Issue 1, Apr 2012.
- Martinho N. A. G., Silva M. C. G. and Ramos J. A. E. (2004). Evaluation of thermal comfort in a vehicle cabin. *Journal Automobile Engineering*. 218: 159-166.

- McLaren C., Null J. and Quinn J. (2005). Heat Stress from Enclosed Vehicles: Moderate Ambient Temperatures Cause Significant Temperature Rise in Enclosed Vehicles. *Pediatrics*. 116(1)(2005). pp 109-112.
- Mezrhab A. and Bouzidi M. (2006). Computation of Thermal Comfort Inside a Passenger Car Compartment. *Applied Thermal Engineering*, 26 (2006). 14-15, pp. 1697-1704.
- Neacsu C.A., Ivanescu M. and Tabacu I. (2009). The Influence of the Solar Radiation on the Interior Temperature of the Car. *European Social Fund (ESFA) 2009*. Bucharest 2009.
- Neacsu C.A., Ivanescu M. and Tabacu I. (2009). The Influence of the Glass Material on the Car Passengers Thermal Comfort. *University of Pitesti Scientific Bulletin XV*. No. 19 (2009).
- Rameshkumar A., Jayabal S., and Thirumal P. (2013). Cfd Analysis of Air Flow and Temperature Distribution in an Air Conditioned Car. *International Refereed Journal of Engineering and Science (IRJES)*. Volume 2, Issue 4(April 2013). ISSN (Online) 2319-183X, (Print) 2319-1821. pp 01-06.
- Rugh J. P., Hendricks T. J. and Koram K. (2001). Effect of Solar Reflective Glazing on Ford Explorer Climate Control, Fuel Economy and Emissions. *Society of Automotive Engineers (SAE) Technical Paper Series*. Paper No. 2001-01-3077.

- Rugh J., Chaney L., Lustbader J., Meyer J., Rustagi M., Olson K. and Kogler R. (2007). Reduction in Vehicle Temperatures and Fuel Use from Cabin Ventilation, Solar Reflective Paint and a New Solar-Reflective Glazing. *Society of Automotive Engineers (SAE) Technical Paper Series*. Paper No. 2007-01-1194.
- Saidur, R., Masjuki, H.H., and Hasanuzzaman, M. (2009). Performance of an Improved Solar Car Ventilator. *International Journal of Mechanical and Materials Engineering (IJMME)*. Vol. 4 (2009), No. 1, 24 -34.
- Sevilgen G. and Kilic M. (2010). Transient Numerical Analysis of Airflow and Heat Transfer in a Vehicle Cabin during Heating Period. *International Journal of Vehicle Design*. Vol 52 (1-4). Pp 144-159.
- Sevilgen G. and Kilic M. (2013). Investigation of Transient Cooling of an Automobile Cabin with a Virtual Manikin under Solar Radiation. *Thermal Science*. Year 2013, Vol. 17, No. 2, pp. 397-406.
- Zhang H., Dai L., Xu G., Li Y., Chen W., and Tao W.Q. (2009a). Studies of Air-flow and Temperature Fields inside a Passenger Compartment for Improving Thermal Comfort and Saving Energy. Part I: Test/numerical model and validation. *Applied Thermal Engineering*. 29(10) (2009) 2022-2027.
- Zhang H., Dai L., Xu G., Li Y., Chen W., and Tao W.Q. (2009b). Studies of Air-flow and Temperature Fields inside a Passenger Compartment for Improving Thermal Comfort and Saving Energy. Part II: Simulation Results and Discussion. *Applied Thermal Engineering*. 29 (2009) 2028-2036.